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# Revving in Profit from the Used Luxury Car Market using Survival Analysis Techniques:

# A Case of the German Used Luxury Car Market

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- Methodology
- Data and Results
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Introduction

# Introduction

- The German automobile industry
  - one of the most developed production sectors
  - also generates additional turnover on the used car market
  - above 53 billion Euro in 2008 raising to more than 63 billion Euro in 2012

# Introduction

- The German used car market is organized in three business segments:
  - new car dealers
  - used car dealers
  - private offers

# Introduction

- The used car landscape significantly changed since the introduction of the new warranty law (Gewährleistungsgesetz) in 2002:
  - Privately sold car sales go down from 53% in 2002 to 39% in 2015) and gives way to professional dealers

# Introduction

- Professional dealerships acquire used cars:
  - rental and leasing disposals
  - trade-ins for a new car
  - cars directly bought from private owners

- Challenges:
  - Inflexibility of prices
  - Oversaturated markets

An optimization query arises:
How do we maximize profits by carefully balancing the asking price for a car with the number of days it spends on the market before being resold?

# Introduction

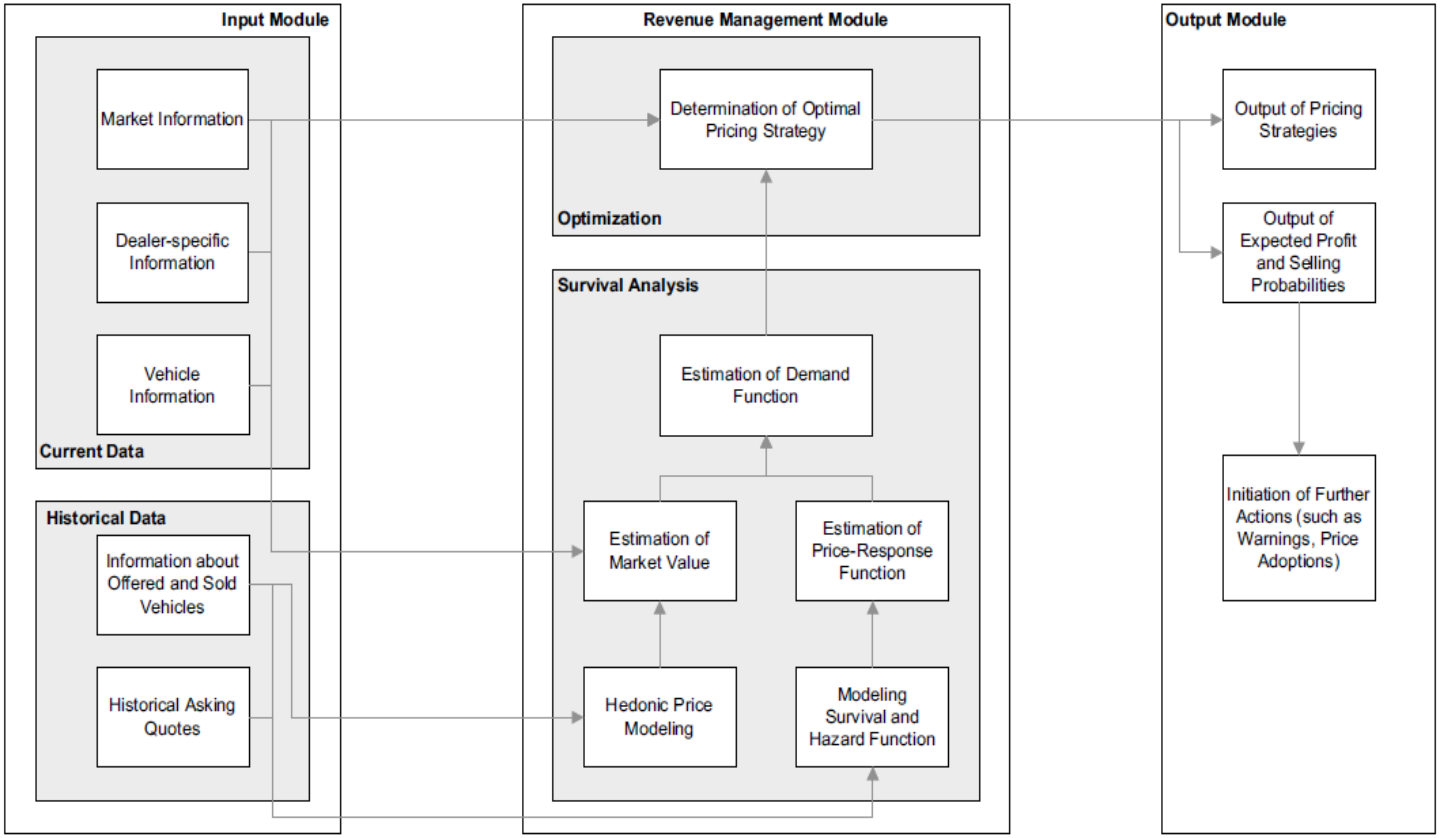


Figure 1.1: Revenue management tool for the used car sector (Jerenz, 2008, p.28).

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# Methodology

# Methodology

## Survival Analysis (SA):

- ”survival analysis” came into being from initial studies, where the event of interest was death
- after World War II, there was new area of SA emerged originating from reliability of military equipment
- Nowadays, the framework is constantly conquering new fields of application, especially in the business domain
- is modeling price response functions for price optimization on markets with restricted goods, such as the used car market

## Common terms in Survival Analysis (SA):

- Event: a car being sold at a specific time point
- Time-to-event/Time-on-market (days): the time between the first day a car entry was uploaded online and:

a) an event (e.g. car being sold), or

b) end of the study.

c) loss of contact or withdrawal from the study

## Common terms in Survival Analysis (SA):

Right censoring:
Subjects for which we do not observe the full time-to-event are described as right censored

Left truncation/interval censoring:
Not fully observed from beginning to end during the studywhere only the status of the event is known

# Methodology

**Survival Function:**
The probability a car is still not sold after a certain period online.

$$S(t) = P(T > t)$$

For car entries which are not censored:

$$P(T = T_i|\theta) = f(T_i|\theta)$$

where $T_i$ refers to the measured time a car spent on the market. The real time for which the car was sold (T) coincides with $T_i$ and θ refers to a set of covariates that influences the time-to-event.

# Methodology

## Survival Function

Right censored data (probability of survival time being more than observed survival time):

$$P(T > T_i|\theta) = 1 - F(T_i|\theta) = S(T_i|\theta)$$

## Hazard Function:

the instantaneous probability of an event to occur, given that the event has not taken place until now

$$\lambda(t) = \lim_{dt \to 0} \frac{\Pr(t \le T < t+dt)}{dt.S(t)} = \frac{f(t)}{S(t)} = \frac{S'(t)}{S(t)}$$

# Hazard Function

the probability of a car being sold at next instant:

$$H(t) = \int_0^t h(u)du = -\ln S(t)$$

## Standard Statistical Approaches in Survival Analysis (SA):

- Kaplan-Maier Estimator
- Nelson-Aalen Estimator

# Kaplan-Maier Estimator

- non-parametric model for estimating the survival function of time duration data

- provides a step-wise non-increasing function that is based on the difference between total number of survivors $n_i$ and total number of censored observations prior to time point $t_i$

$$\hat{S}(t) = \prod_{t_i<t} \frac{n_i - d_i}{n_i}$$

# Cox Proportional Hazard Model

- ability to estimate the effect of multiple covariates $X_i$ on survival (via the hazard function $h(t|X_i)$), as well as its non-parametric estimation of the baseline hazard functions $h(0)$, which grants more flexibility and thus better fit to the data in comparison to fully parametric models


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Data and
Results

# Data and Results

## Data

- Data was originally assembled in the context of a cooperation between a large German automobile manufacturer and mobile.de
- A database of cars from a mentioned brand, offered online for the period between 18 September 2008 and 18 December 2012.
- This includes a thorough record of daily prices, as well as a number of attributes (e.g. car technical specifications or vendor characteristics).
- The data contains 5,915,774 unique car IDs and 747,102 unique vendor IDs. The prices tables contain 190,323,612 price observations in total and the cars tables - 8,323,386 distinct car attribute descriptions

## Data Preparation

- Analyze Prices, Cars and Vendors datasets
- Merge Data set
- Aggregate Unnecessary Observations

# Assessing the effects of Covariate on TOM

- Kaplan Meier Curves
- Cox Proportional Hazards

# Kaplan Meier Curves

- useful for obtaining an initial overview of the trends in survival data
- Challenge for complex datasets with a number of continuous variables, since it requires creating a factor level for each continuous value recorded

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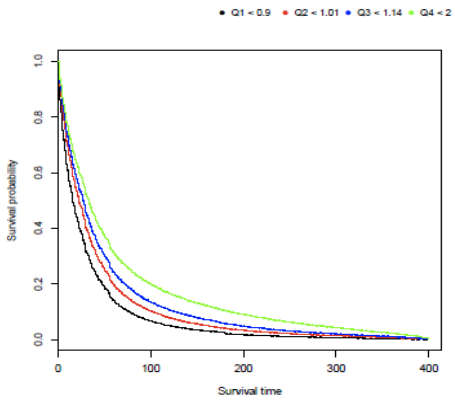
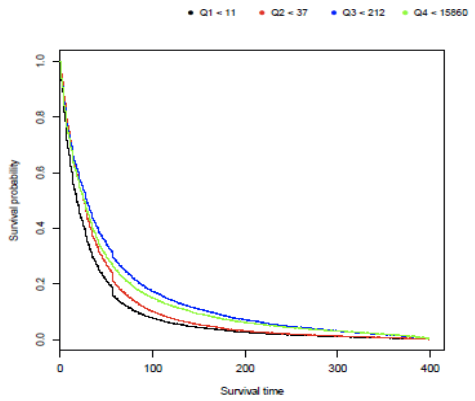
- useful for obtaining an initial overview of the trends in survival data
- Challenge for complex datasets with a number of continuous variables, since it requires creating a factor level for each continuous value recorded
- Degree of Over Pricing (DOP), Market Size (MS), Quantile of Car Price, Age, Dealership size grouped into quantiles

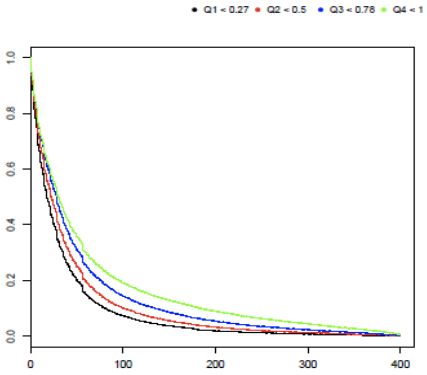
# Kaplan Meier Curves



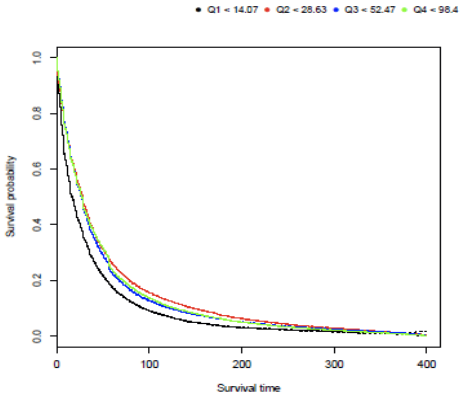

(a) Survival functions for DOP in quartiles.




(b) Survival functions for MS in quartiles.




(c) Survival functions for Q in quartiles.




(d) Survival functions for age in quartiles.

# Kaplan Meier Curves

DOP and Quantile

- cars priced relatively low in comparison to the market have the lowest chance of survival
- the probability for survival increases with each ascending quartile.

Age

- the youngest cars (first quartile = 14 months or less) do demonstrate a tendency for faster sale.
- cars in the higher quartile ranges (28 months or more) are more likely to be sold than cars with age in the second quartile

## Kaplan Meier Curves

Market Size

- cars with small competition on the market (first and second quartile) have lowest survival probabilities

- The survival curves for market size in the third and fourth quartile have interchanged

- the difference between a large market size due to general high production for a car type, which is related to its popularity on the market (for values in the fourth quartile) and a mere large supply with lower customer base (third quartile).

# Kaplan Meier Curves

Vendor Size

- reveals that the largest dealerships (with more than 2500 cars on the market for the examined period) manage to sell their cars fastest on average.

- this might be explained by a tacit know-how and better marketing for large dealerships

- the lowest survival curve crosses both the curves of the second and third quartile.

- the presence of a number of dealerships with less than 10 cars on the market (private offers).

# Data and Results

- The observed intersection of survival curves and non-monotonic arrangement of survival probability along quartiles, hint at possible non-liner relations between variables and a lack of proportionality in hazards for different data groups.

- might be due to the univariate examination of the effects of covariates on survival.

- Cox Proportional Hazards framework

# Data and Results

## Cox Proportional Hazards Model

| | Dependent variable | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Time on market (in days) | | | | | | | |
| | A | B | C | E | M | S | SL | SLK |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Market size | 1.000*** | 0.999*** | 0.999*** | 0.999*** | 0.997*** | 0.998*** | 0.999*** | 0.998*** |
| DOP | 0.300*** | 0.398*** | 0.321*** | 0.379*** | 0.317*** | 0.257*** | 0.283*** | 0.513*** |
| Quantile | 0.841*** | 0.710*** | 0.835*** | 0.755*** | 0.746*** | 1.037** | 0.889*** | 0.578*** |
| Age | 0.994*** | 0.995*** | 0.994*** | 0.996*** | 0.994*** | 0.988*** | 1.002*** | 0.996*** |
| Size vendor | 1.009*** | 1.008*** | 1.007*** | 1.006*** | 1.005*** | 1.003*** | 1.005*** | 1.006*** |
| Observations | 466,048 | 279,333 | 681,465 | 513,884 | 126,469 | 81,529 | 24,955 | 91,901 |
| $R^2$ | 0.116 | 0.097 | 0.083 | 0.067 | 0.091 | 0.080 | 0.065 | 0.093 |
| Max. Possible $R^2$ | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Log Likelihood | -4,111,137.000 | -2,267,910.000 | -5,710,268.000 | -4,073,737.000 | -915,396.800 | -536,513.300 | -150,094.000 | -651,078.700 |
| Wald Test (df = 5) | 57,624.660*** | 27,713.880*** | 56,778.420*** | 34,138.110*** | 11,176.410*** | 6,638.950*** | 1,694.180*** | 8,598.460*** |
| LR Test (df = 5) | 57,669.120*** | 28,400.600*** | 58,967.620*** | 35,511.800*** | 12,005.200*** | 6,779.878*** | 1,676.916*** | 8,938.150*** |
| Score (Logrank) Test (df = 5) | 57,228.840*** | 27,198.330*** | 55,774.100*** | 33,865.190*** | 10,946.070*** | 6,550.558*** | 1,675.045*** | 8,439.512*** |

*Note:* *p<0.1; **p<0.05; ***p<0.01

**Comparing buyers' preferences of a major Mercedes Benz classes**

# Cox Proportional Hazards Model

Market Size

- a negative influence on the car's probability of being sold at next instant.

DOP

- which decreases the probability of a car being sold at next instant by a value between 50% to above 70% for one unit increase in DOP, depending on the car class

# Cox Proportional Hazards Model

Quantile

- increase in the variable decreases the car's probability of being sold at next instant by somewhere between 10% and 40% depending on the car class

Age

- an additional month in age, decreases the chance of a car purchase by 0.5%

Dealership

- An increase of 10 cars in the vendor portfolio, increases the chance of a car being sold by up to 1%.

## Cox Proportional Hazards Model

- However, linearity and proportional of hazards were a concern with this dataset.
- Data-driven techniques were looked into:
- Decision trees and Random Forest

# Decision Trees and Random Forest

Advantages

- potentially reveals interactions between covariates (their non-parametric nature)

- binary splitting rules facilitates easy identification of vehicle profiles with similar survival times

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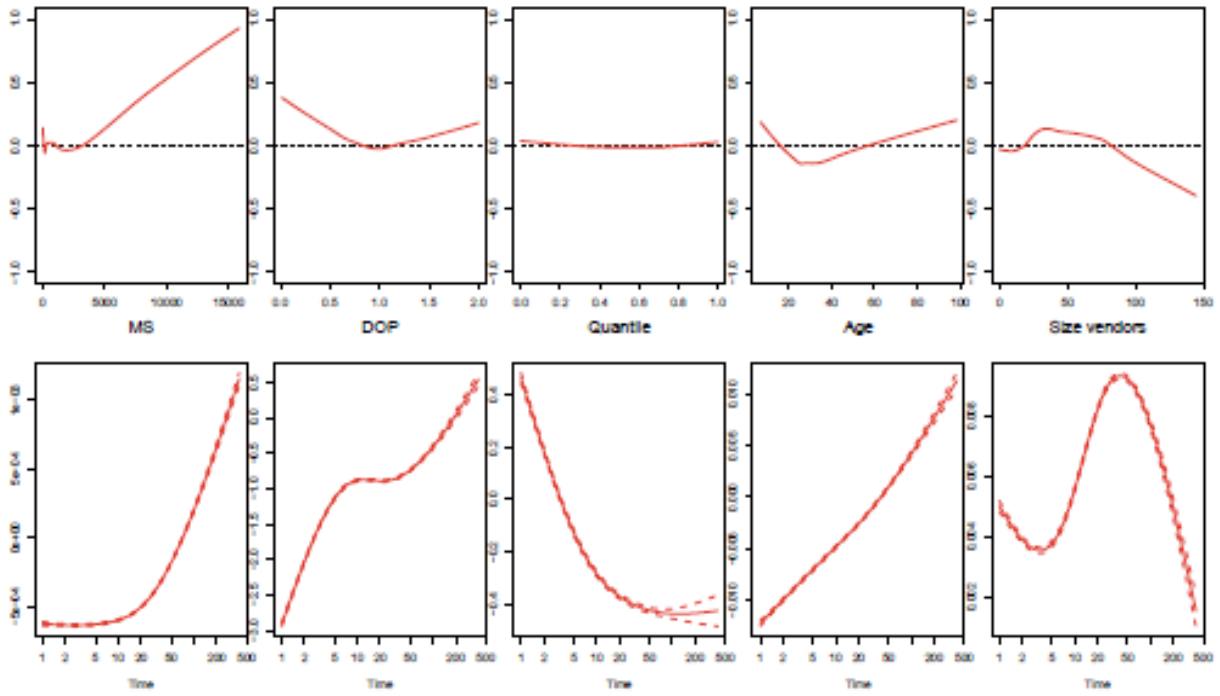
# Decision Trees and Random Forest

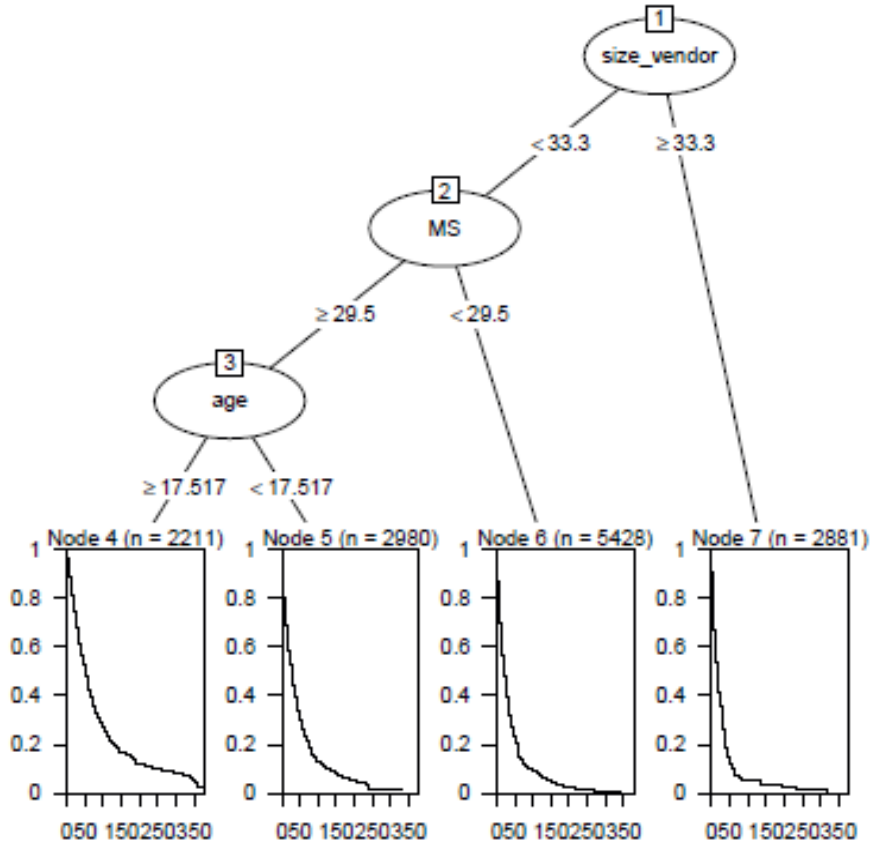
Martingale (linearity) and Schoenfeld residuals (proportionality) for single covariates



# Data and Results

## Decision Tree

- 13500 observations



# Random Forest

- Tune parameters
- Apply model to training data

# Random Forest

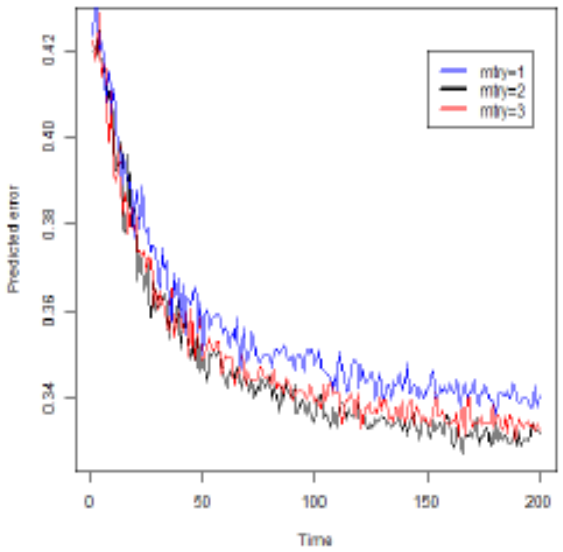
Advantages

- potentially reveals interactions between covariates (their non-parametric nature)

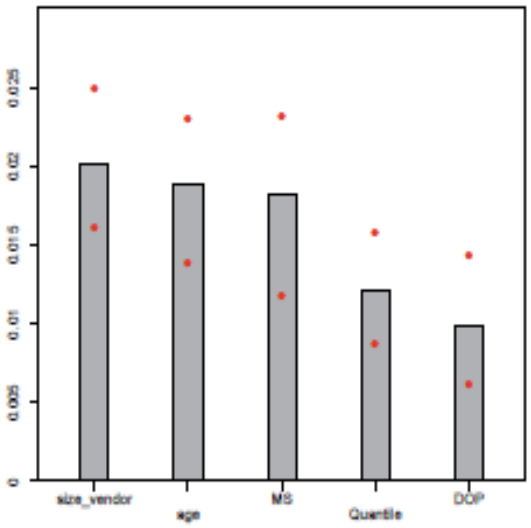
- binary splitting rules facilitates easy identification of vehicle profiles with similar survival times

# Data and Results

## Random Forest




(a) Tuning tree parameters - check predicted error stability across changing number of trees and variables at each split. Number of obsertvations - 20.000.




(b) Variable importance for the five covariate - mean values from a sample of 100 models. Red points indicate maximal and minimal values.

# Random Forest

## Covariates Analysis

Brier Scores

| | IBS |
|---|---|
| Full model | 0.090 |
| w/o vendor size | 0.096 |
| w/o age | 0.096 |
| w/o Quantile | 0.096 |
| w/o DOP | 0.094 |
| w/o MS | 0.094 |

## Random Forest

- Predictions are made on a random sample of 1,500 observations from a validation set.
- Results: vendor size, age and Quantile as the variables which lead to highest improvement of explanatory power.
- DOP and MS

# Conclusion

Statistics Approach

- DOP and Quantile

Data Driven

- Dealership and Age

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# Thank you
# Terima Kasih
# Xie Xie